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for

COMPREHENSIVE PLASMA INSTRUMENTATION (CPI) FOR THE GEOTAIL SPACECRAFT

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Comprehensive Plasma Instrumentation (CPI) for the Geotail Spacecraft:

Final Technical Report

Introduction

Geotail was launched on 24 July 1992 as the first new spacecraft of the International Solar Terrestrial Physics Program (ISTP). A primary objective of the Geotail mission is the acquisition of particles and fields measurements in the tail region of the magnetosphere. The mission is designed with two distinct phases. The initial phase is primarily an exploration of the distant tail. A series of orbits with apogee in the magnetotail at distances from Earth between 80 and 220 Earth radii is achieved using spacecraft propulsion and lunar gravitational assists. During the second phase of the mission the orbital apogee is reduced so that measurements are acquired in the near-tail at distances from Earth 10 to 30 Earth radii. The orbital design also provides for valuable sequences of observations in the solar wind and near the dayside magnetopause that separates the terrestrial magnetosphere from the interplanetary medium. Some of the specific scientific objectives of the Geotail mission are; (1) assessment of the relative importance of solar-wind and ionospheric sources to the plasmas of the magnetotail, (2) a search for plasmoids and flux ropes, (3) direct observation of the effects of plasma acceleration and heating in the current sheet, and (4) measurements of currents and convective flows carried by magnetotail plasmas.

The Comprehensive Plasma Instrumentation (CPI) on board the Geotail spacecraft provides observations of the charged particles that comprise the plasma populations of the magnetosphere and the solar wind. In many cases the physical processes that contribute to the flow of energy and mass through the Solar-Terrestrial plasma system can be understood only through a detailed examination and analysis of the distribution of particle velocities in the ambient plasmas. The Comprehensive Plasma Instrumentation provides detailed measurements of these distributions. To achieve the resolution required to fully characterize the plasma velocity distributions in the different regions traversed by the Geotail spacecraft the Comprehensive Plasma Instrumentation employs three plasma analyzers. (1) a Hot Plasma analyzer (CPI-HP) for hot electrons and ions found in the plasma sheet and the inner magnetosphere. (2) A Solar Wind analyzer (CPI-SW) for cool plasmas with high bulk speeds such as those found in the solar wind and the magnetosheath. (3) An Ion Composition analyzer (CPI-IC) for identification of ion species such as H+, He+, He++, and O+. Along with measurements from other fields and particles instrumentation on Geotail the measurements from CPI provide a fundamental experimental base for investigations of solar-terrestrial plasmas and fields. The CPI has been in essentially continuous operation since October 1992 and continues to return high resolution measurements of magnetospheric and interplanetary plasmas.

Post-launch activities at the University of Iowa supported by this contract include: (1) Daily monitoring of instrument housekeeping and science data and support for periodic commanding of the instrumentation to ensure safety of the instrumentation and adequate data quality. (2) Development of computational algorithms and computer software required to process the instrument data into forms suitable for scientific analysis. The software is developed for use at the University of Iowa and software is also provided for computation of Key Parameter data files that are produced and maintained by the Central Data Handling Facility (CDHF) at Goddard Space Flight Center. (3) Processing of data. This includes the computation of quantitative plasma parameters and production of hard-copy survey plots used in scientific analyses. (4) Scientific research in accordance with the goals of the Geotail mission and ISTP. This includes research projects initiated by personnel at the University of Iowa and support of research in collaboration with other ISTP research groups. (5) Presentation of research results at professional meetings and in peer-reviewed publications.

Instrument Operations and Monitoring

Real-time data from CPI are available when the spacecraft is visible from the Usuda tracking station in Japan. These data are received and processed at the Institute of Space and Astronautical Science (ISAS) in Japan. The CPI PI team maintains a computer on site at ISAS that accesses this data stream. A connection between the computer at ISAS and computers at the University of Iowa is accomplished via a Decnet link to ISAS. Personnel from the CPI PI team monitor the data on a daily basis and check instrument voltages, temperatures, and other operational parameters to ensure that the instrumentation is operating in a safe state and providing optimal return of measurements. In addition, quick look data from tape recorder dumps are made available several times per day by the Central Data Handling Facility at Goddard Space Flight Center, and these data are reviewed on a daily basis.

The plasma analyzers utilize high voltages to bias the sensors and to provide energy analysis of the ambient plasmas. During spacecraft maneuvers there is risk that gas plumes from the thrusters may impinge on the CPI analyzers and cause high-voltage arcs that could damage the instrumentation. At these times a sequence of commands designed by the CPI PI team is sent from ISAS to the spacecraft. These command sequences reduce instrument voltages prior to a maneuver and safely restore them after the maneuver. As these commands are sent the status of the CPI is monitored by CPI PI team personnel at the University of Iowa using the Decnet link to ISAS. Communication with the ISAS operation center is maintained so that the safety of the instrumentation is not compromised during these critical operations.

Data Processing

The CPI telemetry stream consists of engineering data used to monitor the status of the instrumentation plus responses from the 35 sensors incorporated in the instrumentation. This telemetry is received at the University of Iowa on compact disks provided by the Central Data Handling Facility (CDHF) at Goddard Space Flight Center. Instrument calibrations and algorithms developed by the PI team are used to process the telemetry and produce computer files and graphical output suitable for scientific analyses. In plasma physics the distribution of particle velocities is a fundamental quantity. These distributions can be quite complex. The sensor responses from CPI comprise a record of the plasma velocity distributions near the spacecraft. The CPI-HP analyzer provides complete sets of energy-angle samples for the electron and ion velocity distributions approximately three times each minute. The CPI-SW analyzer acquires a full set of high-resolution samples of the ion velocity distributions repeated approximately every 48 s.

An initial step in the processing is the production of Energy-time spectrograms that display the measured particle intensities as a function of energy, direction, and time in formats sufficiently condensed so that it is possible to obtain an overview of the state of the plasmas. These spectrograms are an invaluable tool for initial surveys of the plasma environments encountered by the spacecraft. Complete spectrogram sets for the CPI-SW and CPI-HP analyzers are maintained in hardcopy form at the University of Iowa. One complete set of CPI-HP spectrograms is also provided for use by the Geotail Epic PI team. Spectrograms from the CPI-IC unit are produced as needed to provide mass identification.

The CPI-SW and CPI-HP measurements are also used to compute plasma parameters that provide a summary account of the state of the plasmas. These plasma parameters include, but are not limited to, the plasma number density (particles/cm^3), the bulk-flow velocity (km/s), and the temperatures of ions and electrons (K). To maintain the high quality of these parameters instrument calibrations are periodically reviewed and updated. Revised calibrations are incorporated in the computational algorithms used to compute parameter files at the University of Iowa. In addition, a similar set of software is provided by the PI team to the CDHF for computation of parameters that are included in the CPI Key Parameter files available to ISTP investigations. The software provided to the CDHF is designed to compute robust good-quality parameters but uses only a subset of the possible detectors so that the results will be insensitive to small variations of instrument calibrations. Thus the parameters can be made available to the research community in a timely fashion.

The spectrograms and plasma parameters are produced routinely for all available data. Other analysis products are produced on a campaign basis, i.e. as needed to support various individual investigations. The computer software tools used in the analysis of the plasma measurements are often dependent on the details of a particular investigation, and the development of analysis algorithms and software is an ongoing process. The specialized software that has been developed so far includes programs that provide graphical representations of individual particle velocity distributions. These visualization programs are an important tool for comparisons with theory and simulations. Computer software that computes quantitative physical parameters based on a combined set of plasma and magnetic field data has also been developed. The magnetic field data is provided by the Geotail MGF

PI team. Parameters that are now available include total pressure (magnetic plus particle), plasma beta, and field-aligned components of particle velocities and electric currents. Moments computed for limited sets of energies and directions are also available.

Research Efforts

A copy of the initial publication that describes the CPI and details some initial observations is included as part of this report [Frank et al., Journal of Geomagnetism and Geoelectricity, Volume 46, pp. 23-37, 1994]. Research results supported under this contract have been reported at four meetings of the American Geophysical Union, at the International Conference on Substorms-2, and at the Eighth International Symposium on Solar Terrestrial Physics. A series of papers based on this research has been published in peer-reviewed journals. A list of presentations and publications that were completed or initiated under this contract is appended to this report. This list includes reports on research led by CPI investigators at the University of Iowa, by CPI Co-Investigators at other research centers, and reports produced in collaboration with scientists associated with other Geotail instrument teams. A summary of some of this work is given below.

Measurements from the CPI Hot Plasma analyzer have been processed to compute one-minute averages of plasma densities, temperatures, and velocities for the period 1 October 1992 through 31 July 1993. These parameters are used in a preliminary survey of the magnetotail for distances from Earth 10 to 210 Earth radii. Average parameter values and the range of parameter values are given for the center of Earth's magnetotail. The survey characterizes hot plasmas in the plasma sheet and cold plasmas in the vicinity of the plasma sheet. This work includes the thermal ion plasmas for which observations in this range of distances previously had been unavailable. One unanticipated result is the pervasive observation of cold tailward-streaming plasmas within the distant magnetotail. The source of these plasmas appears to be primarily the solar wind. Entry into the magnetotail occurs either at the nose of the magnetosphere or along the flanks. The evolution of cold streaming plasmas subsequent to magnetotail entry is researched by CPI Co-Investigator G. Siscoe and colleagues at Boston University.

The cold plasmas within the magnetotail drift towards the midplane and are thought to be a principal source for the hot plasma sheet. A remarkable result from Geotail is the observation of cold ion beams that persist as distinct components in the presence of hot plasma-sheet plasmas. Previously, such complex non-Maxwellian distributions with hot and cold components had been observed only during the magnetotail traversal of the Galileo spacecraft. Cold ions that encounter the distant X line or the neutral sheet at the center of the plasma sheet are accelerated and eventually may be heated or isotropized. The cold ions in the distant plasma sheet observed by CPI appear to be cold source plasmas at an early stage of this processing. Eventually these ions may become part of the hot isotropic plasma sheet near Earth, or may be ejected as streams into the plasma sheet boundary layer. However, the physical processes that lead to the development of these regions are not well understood. Interpretation of the Geotail observations in terms of nonadiabatic particle motion is proceeding in collaboration with the theory group at UCLA led by M. Ashour-Abdalla. This work is expected to contribute to our understanding of the formation of the plasma sheet and its boundary layer.

The development and evolution of plasmoids is a topic of considerable interest in studies of the magnetotail and magnetospheric substorms. The standard model of a plasmoid pictures a disconnected magnetic island filled with hot plasmas that is expelled from the magnetotail as one part of the process of magnetic substorms. Previous observations of plasmoids in the distant tail did not include measurements of the thermal ions which are essential for a complete understanding of the plasma dynamics. A number of possible plasmoids have been identified in the Geotail data set by D. Fairfield at GSFC based upon reversals of the Z component of the magnetic field as observed with the MGF instrumentation. An intensive study of the electron and ion velocity distributions and the plasma parameters for several of these events reveals unexpected features. Within the region of the plasmoid, as identified from the magnetic signature, the electrons are counterstreaming along the magnetic field indicating that these particles are trapped in a closed or bounded magnetic topology. However, the ion distributions are found to be complex with separate hot and cold components. The bulk velocities of the electrons and the hot ions are the same, but the cold ions have lower speeds. Thus the bulk speed of the electrons is different from the bulk speed of the combined cold and hot ions, and an electric current must exist. The current is consistent with the large dawn-dusk component of the magnetic field that is observed in these cases. This transverse field seems to be a common feature of plasmoids, but it is not accounted for by the standard model of comoving ions and electrons trapped in a magnetic island. The plasma and the magnetic field measurements from Geotail suggest that many of the cases identified as plasmoids may be more akin to magnetic flux ropes aligned along the dawn-dusk axis. Geotail provides an excellent in-situ laboratory for study of the development and evolution of these objects which also are known to exist in interplanetary space. Geotail MGF Co-Investigator R. Lepping at GSFC finds that model flux-rope topologies compare well with the observations.

Collaborative work with several Geotail instrument teams and other researchers also is ongoing. Plasma measurements from CPI are used by H. Matsumoto and coworkers in comparison with PWI plasma wave measurements in their investigation of broadband electrostatic waves in the magnetotail and electron cyclotron harmonic emissions at the magnetopause. An investigation of coronal mass ejections and interplanetary shocks utilizing measurements from the CPI Solar Wind analyzer is in progress at Kyoto University. Plasma measurements from CPI also have been provided for use by scientists associated with the MGF, EFD, and EPIC instrument groups.

GEOTAIL-CPI PUBLICATIONS AND PRESENTATIONS

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